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(54) Title: A METHOD OF MAKING A RADIATION-CURABLE, OPTICAL GLASS FIBER COATING COMPOSITION HAVING EXTENDED SHELF LIFE AND SAID COMPOSITION (57) Abstract The invention relates to a radiation-curable resin coating composition having extended shelf life and being adapted for use in forming a radiation-cured coating on an optical glass fiber for signal transmission, which when suitably cured provides reliable and consistent resistance to delamination from the optical glass fiber, said uncured coating composition comprising: a radiation-curable oligomer or monomer, and a coupling agent containing at least one functionally-effective group capable of binding to glass and which is susceptible to hydrolysis under normal shelf storage conditions for said coating composition; said coating composition having a controlled stoichiometric water content less than the stoichiometric amount of said functional groups present in said coupling agent.		

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5 A METHOD OF MAKING A RADIATION-CURABLE, OPTICAL GLASS FIBER COATING
COMPOSITION HAVING EXTENDED SHELF-LIFE AND SAID COMPOSITION

10 1. Field of the Invention.

This invention provides a method for making radiation-curable optical glass fiber coating compositions having an extended shelf-life when comprising a coupling agent, which when suitably cured provide coatings on optical
15 glass fibers having a consistent and predictable resistance to delamination and microbending. The invention also provides a radiation-curable optical glass fiber coating composition, in particular inner primary coatings, having an extended shelf-life made by the above method.

20

2. Description of related art

Optical glass fibers are frequently coated with two or more superposed radiation-curable coatings, which together form a primary coating. The coating which contacts the
25 optical glass fiber is called the inner primary coating and the overlaying coating is called the outer primary coating. In other references, the inner primary coating is often called the primary coating and outer primary coating is called the secondary coating.

30 The inner primary coating is usually a soft coating providing resistance to microbending. Microbending can lead to attenuation of the signal transmission capability of the coated optical glass fiber and is therefore undesirable. The outer primary coating, which is exposed, is typically a
35 harder coating providing desired resistance to handling forces, such as those encountered when the fiber is cabled.

Coating compositions for making inner primary coatings generally comprise a polyethylenically unsaturated monomer or oligomer dissolved or dispersed in a liquid ethylenically unsaturated medium. These coating compositions
5 also generally include a glass adhesion promoter which provides a link between the polymer inner primary coating and the surface of the optical glass fiber. Silane coupling agents have been used as such glass adhesion promoters.

Optical glass fibers are weakened upon exposure to
10 water. For example, moisture in air can cause weakening and the eventual breakage of optical glass fibers. It is therefore desirable that the inner primary coating prevent moisture from attacking the optical glass fiber.

In addition to causing the weakening of the optical
15 glass fibers, moisture can also cause the inner primary coating layer to delaminate from the optical glass fiber. Attenuation would increase as a result of delamination. Further, the delamination of the inner primary coating from the optical glass fiber usually results in a weakened optical
20 glass fiber, because the inner primary coating can no longer protect the optical glass fiber from attack from moisture.

To avoid moisture damage to the glass optical fiber, it is desirable to use a radiation-curable, inner primary, optical glass fiber coating composition that when
25 suitably cured provides a reliable and consistent resistance to delamination from optical glass fibers.

For certain applications, conventional radiation-curable, optical glass fiber coating compositions do not provide cured inner primary coatings having sufficient
30 reliability and consistency in resistance to delamination caused by moisture.

When coated optical glass fibers are soaked in water (hereinafter referred to as "water-soak"), typical optical glass fibers having an inner primary coating made
35 from the same type of material, but different batches,

exhibit different levels of delamination. Thus, known radiation-curable, optical glass fiber coating compositions have the problem of providing cured inner primary coatings having unreliable and inconsistent resistance to delamination.

There is a need for a solution to the above problem and to provide a radiation-curable, inner primary, optical glass fiber coating composition which when suitably cured provides an inner primary coating having improved predictable and consistent adhesion characteristics to the optical glass fiber.

It has also been found that the resistance to delamination of the cured inner primary coating from an optical fiber decreases with aging of the radiation-curable, optical glass fiber coating composition, and this decrease may be erratic from one batch of composition to another.

There is a need for a solution to the above problem of storage stability and to provide a storage-stable, radiation-curable, optical glass fiber coating composition which will exhibit consistent, desired adhesion characteristics.

SUMMARY OF THE INVENTION

An objective of the present invention is to provide a process of making radiation-curable, optical glass fiber coating compositions having extended shelf-life and which when suitably cured provide inner primary coatings having reliable and consistent adhesion characteristics to optical glass fibers.

Another objective of the present invention is to provide a radiation-curable, inner primary, optical glass fiber coating composition having extended shelf-life, which when suitably cured provides consistent and reliable adhesion characteristics to optical glass fibers.

Another objective of the present invention is to

provide a radiation curable optical glass fiber coating composition having extended shelf life, which composition comprises, after aging, a reactive adhesion promotor in a consistent level.

5 Surprisingly, after extensive testing of the many components in radiation-curable optical glass fiber coating compositions, it has been found that the shelf-life of the uncured coating composition and that the final adhesion characteristics of a cured inner primary coating to the
10 optical glass fiber are dependent upon the amount of water present in the uncured coating composition.

The present invention is therefore based on the discovery that the amount of water must be carefully controlled when making the radiation-curable optical glass
15 fiber coating composition to provide an extended shelf-life for the uncured composition and to provide a cured coating having reliable and predictable adhesion characteristics.

In particular, the present invention provides a process for extending the useful shelf-life of radiation-
20 curable resin coating compositions, adapted for use in forming coatings on optical glass fibers for signal transmission, and which contain a coupling agent having a functionally-effective glass binding group and which group is susceptible to hydrolysis under normal shelf storage
25 conditions for the coating composition. The cured coating provides reliable and consistent resistance to delamination from the optical glass fiber.

The process of this invention consists essentially in the steps of establishing and controlling the water
30 content for each component utilized in the preparation of the coating composition such that the ratio of total molar equivalent water content of the final coating composition to the total molar content of the functionally-effective glass binding groups is maintained at a level of less than one.

35 The invention also provides a process for extending

the shelf-life of radiation-curable coating compositions adapted for use in forming coatings on optical glass fibers for signal transmission and containing a coupling agent having a functional group which is capable to bind with glass and which is susceptible to hydrolysis under normal shelf storage conditions for the coating composition. Cured inner primary coatings should provide reliable and consistent adhesion to the optical glass fiber. The process consists essentially in the steps of formulating the coating composition from components having sufficiently low respective water contents such that after formulation the ratio of total molar equivalent water content of the formulated coating composition to the total molar equivalent content of the functional groups is less than one.

In known processes for the formulation or production of radiation-curable coating composition adapted for use in forming coatings on optical glass fibers for signal transmission and including a coupling agent containing at least one functional-effective glass binding group and which is susceptible to hydrolysis under normal shelf storage conditions for the coating composition, the improvement according to the present invention for providing an extended shelf life for the composition consists essentially in the steps of maintaining the total water content of the components used to formulate the composition such that the water content present in the coating composition is an amount less than the stoichiometric amount of water required to react via hydrolysis with the amount of the functional-effective glass binding groups present in the coating composition.

The invention further provides a radiation-curable optical glass fiber coating composition having extended shelf-life and when suitably cured exhibits reliable and consistent resistance to delamination from the optical glass fiber. The coating composition comprises a radiation-curable

oligomer or monomer and a coupling agent containing at least one functionally-effective glass binding group and which is susceptible to hydrolysis under normal shelf storage conditions for said coating composition. The coating
5 composition has a controlled stoichiometric water content less than the stoichiometric amount of the said functional groups present in the coupling agent.

While this invention has been described with reference to radiation-curable, inner primary, optical glass
10 fiber coating compositions, it will be understood that this invention is applicable to radiation-curable, single-coat compositions which are applied to optical glass fibers.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

15 This invention is applicable to all radiation-curable optical glass fiber coating compositions (hereinafter "inner primary composition") containing a coupling agent having a functionally-effective glass binding group and which is susceptible to hydrolysis under normal shelf storage
20 conditions for the inner primary composition. If the coating composition is used as inner primary coating, the coupling agent has a functionally effective glass binding group which bonds with the glass fiber. As inner primary coatings generally contain a coupling agent, this invention is in
25 particular applicable to radiation curable inner primary coatings. However, in case other coatings comprise a coupling agent, this invention is applicable to those coating composition as well. As an example, the further description will describe inner primary coatings.

30 Examples of suitable inner primary compositions include those which are disclosed in U.S. patent numbers 4,624,994; 4,682,851; 4,782,129; 4,794,133; 4,806,574; 4,849,462; 5,219,896; 5,336,563 and 4,932,750 which are incorporated herein by reference.

35 Inner primary compositions contain one or more

radiation-curable oligomers or monomers having at least one functional group capable of polymerization when exposed to actinic radiation. Suitable radiation-curable oligomers or monomers are now well known and within the skill of the art.

5 Commonly, the radiation-curable functionality used is ethylenic unsaturation, which can be polymerized through radical polymerization or cationic polymerization. Specific examples of suitable ethylenic unsaturation are groups containing acrylate, methacrylate, styrene, vinyl ether, vinyl
10 ester, N-substituted acrylamide, N-vinyl amide, maleate esters, and fumarate esters. Preferably, the ethylenic unsaturation is provided by a group containing acrylate, methacrylate, or styrene functionality.

 Another type of functionality generally used is
15 provided by, for example, epoxy groups, or thiol-ene or amine-ene systems. Epoxy groups can be polymerized through cationic polymerization, whereas the thiol-ene and amine-ene systems are usually polymerized through radical
20 polymerization. The epoxy groups can be, for example, homopolymerized. In the thiol-ene and amine-ene systems, for example, polymerization can occur between a group containing allylic unsaturation and a group containing a tertiary amine or thiol.

 The inner primary coating contains a coupling agent
25 having a functionally-effective glass-binding group which bonds with glass fibers and which is susceptible to hydrolysis under normal shelf storage conditions for the inner primary composition. The coupling agent may contain a plurality of glass-binding groups, all of which may not be
30 functionally-effective glass binding groups. Functionally-effective glass-binding groups is used herein to mean those glass-binding groups which are capable of bonding to optical glass fiber. Silane in hydrolyzed form reacts with glass.

 Examples of suitable glass-binding functional
35 groups include methoxy, ethoxy, and butoxy. A specific

example of a suitable coupling agent is γ -mercapto-propyltrimethoxysilane.

The inner primary compositions may also contain a reactive diluent which is used to adjust the viscosity of the inner primary composition. The reactive diluent can be a low viscosity monomer containing at least one functional group capable of polymerization when exposed to actinic radiation. This functional group may be of the same nature as that used in the radiation-curable monomer or oligomer. Preferably, the functional group present in the reactive diluent is capable of copolymerizing with the radiation-curable functional group present on the radiation-curable monomer or oligomer.

For example, the reactive diluent can be a monomer or mixture of monomers having an acrylate or vinyl ether functionality and an C_4 - C_{20} alkyl or polyether moiety. Particular examples of such reactive diluents include:

hexylacrylate,
2-ethylhexylacrylate,
isobornylacrylate,
decyl-acrylate,
laurylacrylate,
stearylacrylate,
2-ethoxyethoxy-ethylacrylate,
laurylvinylether,
2-ethylhexylvinyl ether,
N-vinyl formamide,
isodecyl acrylate,
isooctyl acrylate,
vinyl-caprolactam,
N-vinylpyrrolidone, and the like.

Another type of reactive diluent that can be used is a compound having an aromatic group. Particular examples of reactive diluents having an aromatic group include:
ethyleneglycolphenylether-acrylate,
polyethyleneglycolphenyletheracrylate,

polypropyleneglycolphenylether-acrylate, and alkyl-substituted phenyl derivatives of the above monomers, such as polyethyleneglycolnonylphenyl-etheracrylate.

The reactive diluent can also comprises a diluent
5 having two or more functional groups capable of
polymerization. Particular examples of such monomers include:
C₂-C₁₈ hydrocarbon-dioldiacrylates,
C₄-C₁₈ hydrocarbondivinylethers,
C₃-C₁₈ hydrocarbon triacrylates, and the polyether analogues
10 thereof, and the like, such as 1,6-hexanedioldiacrylate,
trimethylolpropanetri-acrylate, hexanedioldivinylether,
triethylene-glycoldiacrylate,
pentaerythritol-triacrylate,
ethoxylated bisphenol-A diacrylate, and tripropyleneglycol
15 diacrylate.

If the radiation-curable functional group of the
radiation-curable monomer or oligomer is an epoxy group, for
example, one or more of the following compounds can be used
as the reactive diluent:
20 epoxy-cyclohexane,
phenylepoxyethane,
1,2-epoxy-4-vinylcyclohexane,
glycidylacrylate,
1,2-epoxy-4-epoxyethyl-cyclohexane,
25 the diglycidylether of polyethylene-glycol,
the diglycidylether of bisphenol-A, and the like.

If the radiation-curable functional group of the
radiation-curable monomer or oligomer has an amine-ene or
thiol-ene system, examples of reactive diluents having
30 allylic unsaturation that can be used include:
diallylphthalate,
triallyltri-mellitate,
triallylcyanurate,
triallylisocyanurate, and
35 diallylisophthalate. For amine-ene systems, amine functional

diluents that can be used include, for example:
the adduct of trimethylolpropane, isophorondiisocyanate and
di(m)ethylethanolamine,
the adduct of hexanediol, isophoronediiisocyanate and
5 dipropylethanolamine, and
the adduct of trimethylol propane,
trimethylhexamethylenediisocyanate and
di(m)ethylethanolamine.

Other additives which can be used in the inner
10 primary composition include, but are not limited to, light
sensitive and light absorbing components, photoinitiators,
catalysts, lubricants, wetting agents, antioxidants and
stabilizers. The selection and use of such additives is
within the skill of the art.

15 After extensive testing, it has now been found that
even if only a small amount of water is present in the inner
primary composition as it is formulated, there can be a
hydrolytic reaction during normal shelf storage conditions
for the composition. It appears that this reaction occurs
20 with the glass-binding functional groups (i.e., Si-OR)
present in the coupling agent. In this manner, the intended
content of the functionally-effective glass-binding groups
will be significantly modified and reduced during normal
shelf storage. As a result, the intended and expected
25 performance of the coating composition when used may be
erratic and inconsistent and degraded. The reduction in the
amount of functionall-effective glass-binding functional
groups appears to lead to the unreliable and inconsistent
adhesion performance characteristics exhibited by the final
30 cured, inner primary coating. In effect, the coating obtained
from such a composition after a period of shelf-storage under
normal conditions will be significantly degraded from that
obtained from a freshly prepared composition. At present, to
reliably obtain the desired, undegraded coating performance
35 characteristics, the composition should be used within a

relatively short storage time period. That is, the water content of the composition leads to a significantly reduced shelf-life for the uncured inner primary composition.

Therefore, during production of the inner primary composition, the amount of water should be carefully controlled to be less than the amount of water necessary to react with the functionally-effective glass-binding groups so that a substantial part of the functionally-effective groups will be present at the time of use and application of the inner primary composition for radiation-cure on the optical glass fiber.

This amount of water includes any water initially present in the components of the inner primary composition, as well as any water introduced during the formulation of the inner primary composition. Water introduced during packaging and re-packaging of the inner primary composition should also be considered.

Preferably, at least 5% of the functionally effective alkoxy groups is retained after storage for 100 days at normal shelf storage temperatures. More in particular, at least 50% of the functionally effective groups is retained.

Hence, preferably the components contain little or no water in particular less than 0.01 wt.%. Each batch of raw material preferably is quality screened to determine the water content prior to inclusion in the composition. Furthermore, making and (re)packaging of the coating composition preferably is done under anhydrous conditions. Thus, components comprising the least amount of water are preferred according to the invention. However, a man skilled in the art is able to determine an acceptable amount of water which still gives a storage stable coating. Hence economic considerations may lead to components with an acceptable amount of water, as long as the teaching of this invention is adhered to.

Methods for determining the amount of water in inner primary compositions are known in the art. For example, the amount of water present in the components used to make the inner primary composition and the amount of water in the inner primary composition formed can be measured via the well-known Karl-Fischer titration method. An example of the Karl-Fischer titration method is described in the Example section hereinbelow.

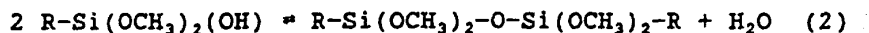
Usually, the amount of water should be carefully controlled to be less than the stoichiometric amount of water which will react with the functionally-effective glass binding groups which are present. Thus, for each equivalent of said groups the amount of water should be controlled to be less than one equivalent.

When determining the amount of water allowable in the inner primary composition, the effects of hydrolysis of one or more of the said functional groups on other non-hydrolyzed, functionally-effective glass binding functional groups should be considered. For example, by hydrolyzing one of the glass binding functional groups on the coupling agent, the remaining non-hydrolyzed functional groups may no longer be capable of binding to glass. In this manner, the stoichiometric amount of water to the said functional groups may be less than the actual number of such groups originally present in the coupling agent before being effected by water. More particularly, it is recognized that while three functional groups may be present on the coupling agent only one of these will be effective for adhesion promotion and glass binding functionality. If one such group is hydrolyzed the other two functional groups may be unable to bind effectively to the glass surface. The calculated stoichiometric amount of water in such a case should be with respect to the first, active group and not with respect to the other two inactive (or less active) functional groups.

In some instances, the amount of water which will

be sufficient to hydrolyze all of the functionally-effective glass-binding groups (excluding those functional groups unable to bind to glass after hydrolysis of one or more other glass-binding groups present on the coupling agent) may be significantly less than the calculated stoichiometric amount of water as a result of by-product water generated via autogenous condensation reactions taking place within the composition. If such by-product water is generated, the free water content of the compositional components should be controlled to a level less than the calculated stoichiometric amount of water for reaction with all of the said functional groups.

An example of a coupling agent system which may produce water via condensation is illustrated by the following two reactions:



wherein R is a hydrocarbon, or a hydrocarbon comprising ether groups.

The determination of the amount of water necessary to hydrolyze the functional groups according to the formulae 1 and 2 will be explained by way of the following example for a composition containing 1 wt.% of a trimethoxy γ -mercaptopropylsilane coupling agent. In 100 grams of inner primary composition of the formulated composition, 1 gram of the above mercaptosilane will provide .0051 molar equivalents of functionally-effective glass-binding -Si-OCH_3 groups. This calculation assumes that two of the -Si-OCH_3 groups may be excluded from the equivalence calculation since once one of the three -Si-OCH_3 groups is hydrolyzed the other two are usually functionally ineffective for binding to glass under typical radiation-curing coating conditions.

If there is also present .04 gram of water in the composition, this is effectively .0022 molar equivalents of OH groups. In the hydrolysis reaction of formula 1, .0022 equivalents of water will hydrolyze .0022 equivalents of the functionally-effective glass-binding -Si-OCH₃ groups, leaving
 5 .0029 equivalents of functionally-effective glass-binding -Si-OCH₃ groups in the inner primary composition. However, if after such hydrolysis of the first -Si-OCH₃ groups, one or more of the remaining -Si-OCH₃ groups is functionally-
 10 effective the calculations should be adjusted to include those additional equivalents of -Si-OCH₃ groups. Now, the resulting hydrolyzed mercaptosilane may nonetheless undergo a condensation reaction according to the above formula (2) to generate in situ an additional .0011 equivalents of by-
 15 product water. This additional .0011 equivalents of water is then capable of hydrolyzing an additional .0011 equivalents of functionally-effective glass-binding -Si-OCH₃ groups, and so on.

When the coupling agent selected behaves according to the formulae 1 and 2 under normal storage conditions, the amount of water sufficient to hydrolyze the functionally-effective glass-binding functional groups will be approximately one half of the calculated stoichiometric amount of water for the functionally-effective glass-binding
 25 functional groups. This amount can be approximated by the following equation:

$$X = \sum_{n=0}^{\infty} X_n \quad \text{wherein } X_n = 1/2^{n-1}$$

30 $n = 0$

where $1/X$ equals the equivalents of water necessary to react with one equivalent of the functionally-effective glass-binding functional groups, and n represents the number of
 35 times the hydrolysis and condensation reactions are repeated,

which theoretically is infinite. As n approaches infinity, this formula converges on the number 2. Therefore, 1/2 equivalent of water is sufficient to react with one equivalent of the functionally-effective glass-binding groups.

Based on the disclosure herein, one of ordinary skill in the art will be generally able to determine the equivalents of water which will be effective to hydrolyze the equivalents of the said functionally-effective glass-binding functional groups present in other systems which might exhibit different hydrolysis/condensation reaction behavior other than as illustrated in formulae 1 and 2.

Normal storage conditions of the inner primary composition include shipping and handling of the inner primary composition, as well as the conditions under which the inner primary composition is stored by the end-user prior to application to the glass fibers. Because inner primary compositions are reactive, they are usually stored at room temperature or below. At elevated temperatures the inner primary composition can react. Preferably, the storage temperature is less than about 40°C and greater than the freezing temperature of the composition.

The invention will be further explained by the following non-limiting examples.

Example 1:

The amount of water necessary to hydrolyze the functionally-effective glass-binding groups of gamma-mercaptopropyltrimethoxysilane was determined. Gamma-mercaptopropyltrimethoxysilane contains three alkoxy groups which are capable of binding to glass. It has been found that when one of the three alkoxy groups reacts with water via hydrolysis to form a hydroxyl group the other two alkoxy groups are significantly less active or are entirely unable to effect a bonding of the coating composition with the glass

fiber surface under typical radiation-curing conditions.

It has also been found that the gamma-mercaptopropyldimethoxyhydroxysilane formed from the hydrolysis of gamma-mercaptopropyltri-methoxysilane will
5 undergo an in situ condensation reaction according to the above formula 2 to produce water under normal shelf storage conditions.

Example 2:

- 10 The effect of the amount of water present in radiation-curable, inner primary, glass optical fiber compositions on the adhesion of the cured inner primary coating to glass was tested. Two radiation-curable compositions were made using the components shown in Table 1.
15 The amount of water was varied, as shown in Table 2.

Component	Weight %
Radiation-Curable Oligomer ¹	56
Photoinitiator ²	3
Antioxidant ³	.5
Isodecylacrylate	14
Ethoxylatednonylphenolmonoacrylate	25.5
Gamma-Mercaptopropyltrimethoxysilane	1

¹ HEA-(IPDI-PPG 1025)_{1.06}-(IPDI-Permanol)_{1.14}-

10 IPDI-HEA

HEA = hydroxyethylacrylate

IPDI = isophoronediiisocyanate

PPG1025 = polypropyleneglycol

Permanol = polycarbonatepolyol

15

² 75/25 blend of 2-hydroxy-2-methyl-1-phenyl-
propan-one and
bis(2,6-dimethoxybenzoyl)-2,4,4-
trimethylpentylphosphineoxide

20

³ Thiodiethylene bis(3,5-di-tert-butyl-4-
hydroxy)hydrocinnamate

25

Table 2

Sample	Amount of Water (wt%)	Amount of Effective Adhesion Promoter (wt %)		
		Initial	1 Month	3 Months
1	.02	1.05	1.04	.98
2	.07	.98	.80	.57

Test Procedures

Determination of Water Content:

The water content was determined using a Karl-Fischer titration method, as described in ASTM D 1364. Because it is known that mercaptans interfere with the Karl-Fischer titration method, samples were tested prior to addition of γ -mercaptopropyltrimethoxysilane. Each sample was dissolved in pyridine and titrated directly with Karl-Fischer reagent to an electrometric end point. A catalyst, 1-ethylpiperidine, was added to accelerate the reaction between water and the sulfur dioxide-iodine present in the Karl-Fischer reagent.

A Brinkmann-Metrohm-Herisau apparatus was used. The apparatus included a 658 KF processor, a 655 dosimat, a 681 pump unit, a titration vessel with cover, two dark-glass bottles (one of solvent and the other for surplus liquid), the associated tubing to connect these to the pump and titration vessel cover, and a magnetic stirring bar (teflon coated).

A solvent was made by adding 50 ml of 1-ethylpiperidine to a 1 liter volumetric flask and diluting it to the 1 liter mark with pyridine. The solution was mixed

thoroughly to insure a uniform composition, and poured into the dark-glass bottle that was designated for solvent supply,

The Karl-Fischer reagent was first standardized as follows. The solvent was added to the vessel. The stirring
5 motor was turned on and the speed adjusted so the vortex formed in the solvent was at least 1 cm deep. The "COND" button on the processor keyboard was pressed so that Karl-Fischer reagent was pumped into the vessel until an end point was detected. When the end point was reached, the
10 "ready" light came on. The "Standby" button on the Processor keyboard was then pressed and a light on the keyboard labeled "St.by" came on, indicating readiness for the titration step. 20 to 40 μ l of water was drawn into the 50 μ l syringe and the syringe and water were weighed to the nearest 0.1 mg. The
15 water was then injected into the vessel through the septum on the cover and the emptied syringe was weighed. The weight of the injected water was calculated by the difference in weight measurements obtained. The button labelled "Sample Mass" was pressed and the weight of the water was entered.

20 The process of titration of the water injection by addition of the Karl-Fischer reagent was then started. The solution was light in color, while the Karl-Fischer reagent was dark brown, due to its iodine content. The approach of the end point was signaled by darkening of the liquid in the
25 vessel. The Dosimat stopped adding reagent shortly after the darkening was seen. At the end of the titration, three values were printed on the printer paper: SAMPLE (the weight just entered), TITR. VOL, (in ml) and KFR TITER (in mg/ml). The unit was then reset and the above process was repeated two
30 more times so that a total of three titer determinations were done. The MEAN of the three values was then calculated. The MEAN was then entered as the titer determination.

The amount of water in the test samples was then determined. The following table was used to select the
35 appropriate sample weight based on the expected water content

of the sample:

Expected % H ₂ O	Sample Wt. (g)
0.02-0.5	10
0.5-5.0	1
5.0-10.0	0.1

Based on the expected amount water, an appropriate amount of sample liquid was drawn into a disposable syringe and weighed to the nearest 0.1 mg. The sample was then injected into the vessel. The empty syringe was weighed and the amount of sample was calculated by taking the difference between the weight measurements.

The sample was then titrated. At the end point, a three-line message was printed out: "REF. NO", "TITR. VOL.", and "WATER". This process was repeated for each sample.

The water content of each replicate sample was calculated using the equation:

$$\% \text{ water} = \frac{0.1 \times \text{Wt. water (mg)}}{\text{Wt. Sample (grams)}}$$

The average of the replicates was calculated and reported as the water content of the sample.

Determination of Activity of Coupling Agent:

Following determination of the amount of water using the Karl-Fischer titration method, the mercaptopropyltrimethoxysilane was added to the sample.

A drop of the sample was placed on a clean, dry sodium chloride disk. A spacer was then placed on the disk. This disk was covered with a second disk and pressure was

applied so that the coating spread evenly to the edge of the disks. The film between these disks was free of air bubbles. The coating in the sandwiched disks was cured by exposure to UV light. This procedure was repeated using a different
5 amount of the sample.

An infra-red transmission spectra of the cured samples was obtained using a Nicolet 5SXC with a standard TGS detector, as follows. A spectrum of an empty sample compartment was first obtained and stored in a computer file.
10 The samples were then scanned. The spectrum were then converted to absorbance. Each spectrum in the 700 cm^{-1} to 1000 cm^{-1} region of the spectrum was examined. The maximum absorbance in the 790 cm^{-1} to 920 cm^{-1} region was between 0.5 and 1.3.

Standards of the coating containing approximately 0%, 0.25%, 0.5%, 0.75%, 1.0% and 1.25% of mercaptosilane were made. Cured films of each of the standards were made, in duplicate, using the above procedures. The cured films were then scanned. The mercaptosilane absorbance ratio in each
20 calibration spectrum was calculated. The average absorbance ratio of the two replicates for each calibration standard was determined. Using the absorbance ratio and the concentration of each standard, the equation of the best fit line through the data points using linear regression analysis was
25 obtained. using this equation, the amount of mercaptosilane in the samples was determined from the spectra. The average of the two replicates from each sample was determined and reported.

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C L A I M S

1. A radiation-curable resin coating composition having
extended shelf-life and being adapted for use in forming
5 a radiation-cured coating on an optical glass fiber for
signal transmission, which when suitably cured provides
reliable and consistent resistance to delamination from
the optical glass fiber, said uncured coating
composition comprising:
 - 10 a radiation-curable oligomer or monomer,
and
a coupling agent containing at least one
functionally-effective group capable of binding to
glass and which is susceptible to hydrolysis under
15 normal shelf storage conditions for said coating
composition;
said coating composition having a controlled
stoichiometric water content less than the
stoichiometric amount of said functional groups present
20 in said coupling agent.
2. A radiation-curable resin coating composition according
to claim 1, wherein said coupling agent contains a
silane group.
3. A radiation-curable resin coating composition according
25 to any one of claims 1-2, wherein said functional group
is an alkoxy group.
4. A radiation-curable resin coating composition according
to claim 2, wherein said coupling agent is a mercapto-
functional silane coupling agent having a functional
30 alkoxy group.
5. A radiation-curable resin coating composition according
to any one of claims 1-4, wherein at least 5% of the
functionally effective alkoxy group is retained after
storage for 100 days at normal shelf storage
35 temperatures.

6. A radiation-curable resin coating composition according to any one of claims 1-5, wherein the composition is formulated for use as an inner primary coating, and wherein the coupling agent has at least one functionally-effective group capable of bonding to said glass fiber.
7. In processes for the formulation or production of radiation-curable coating composition adapted for use in forming coatings on optical glass fibers for signal transmission and including a coupling agent, said coupling agent containing at least one functionally-effective group capable of bonding to glass and which is susceptible to hydrolysis under normal shelf storage conditions for said coating composition, the improvement for providing an extended shelf-life for said coating composition, which when suitably cured provides reliable and consistent resistance to delamination from the optical glass fiber, consisting essentially of the steps of:
- maintaining the total water content of the components used to formulate said coating composition such that the water content present in said coating composition is an amount less than the stoichiometric amount of water required to react via hydrolysis with the amount of said functional groups present in said coating composition.
8. A process according to claim 7, wherein said step of maintaining the water content further consists essentially of maintaining the water content of each of the components used to formulate said coating composition such that the water content of the coating composition is in an amount less than the stoichiometric amount of water required to react via hydrolysis with the amount of said functional groups present in said

coating composition.

9. A process according to any one of claims 7-8, wherein said coupling agent is a mercapto-functional silane coupling agent having at least one functional alkoxy group and said step of maintaining the water content further consists essentially of maintaining the water content of the components used to formulate said coating composition such that the ratio of the total molar water content of said coating composition to the hydrolysis number of said coupling agent is less than one.
10. A process for extending the shelf-life of radiation-curable resin coating compositions adapted for use in forming coatings on optical glass fibers for signal transmission and containing a coupling agent, which when suitably cured provides reliable and consistent resistance to delamination from the optical glass fiber, said coupling agent having a functionally-effective group which is capable of binding with glass and which is susceptible to hydrolysis under normal shelf storage conditions for said coating composition,
- consisting essentially of the steps of:
- establishing the water content for each component utilized for the preparation of the coating composition such that the ratio of total molar water content of the final coating composition to the total molar content of said functional groups is less than one.
11. A process for extending the shelf-life of radiation-curable resin coating compositions adapted for use in forming coatings on optical glass fibers for signal transmission and containing a coupling agent, which when suitably cured provides reliable and consistent resistance to delamination from the optical glass fiber, said coupling agent having a functionally-effective

group which is capable of binding with glass and which is susceptible to hydrolysis under normal shelf storage conditions for said coating composition,

- 5 consisting essentially of the steps of:
 formulating the coating composition from components
 having sufficiently low respective water contents
 such that after formulation the ratio of total
 molar water content of the formulated coating
10 composition to the total molar content of said
 functional groups is less than one.

12. A process according to any one of claims 7-11, wherein
 the resin composition is formulated for use as an inner
 primary coating, and wherein the coupling agent has at
15 least one functionally effective group capable of
 bonding to said glass fiber.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/NL 97/00257

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C03C25/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 95 15928 A (DSM NV) 15 June 1995 see page 3, line 13 - page 4, line 15 ---	1-12
A	WO 95 23772 A (DSM NV) 8 September 1995 see page 3, line 1 - line 36 ---	1-12
A	US 5 461 691 A (SCHUNCK STEPHAN ET AL) 24 October 1995 see the whole document ---	1-12
A	US 5 219 896 A (COADY CLIVE J ET AL) 15 June 1993 cited in the application see the whole document -----	1-12

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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- * "P" document published prior to the international filing date but later than the priority date claimed

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INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

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